Confidence sharing: an economic strategy for efficient information flows in animal groups

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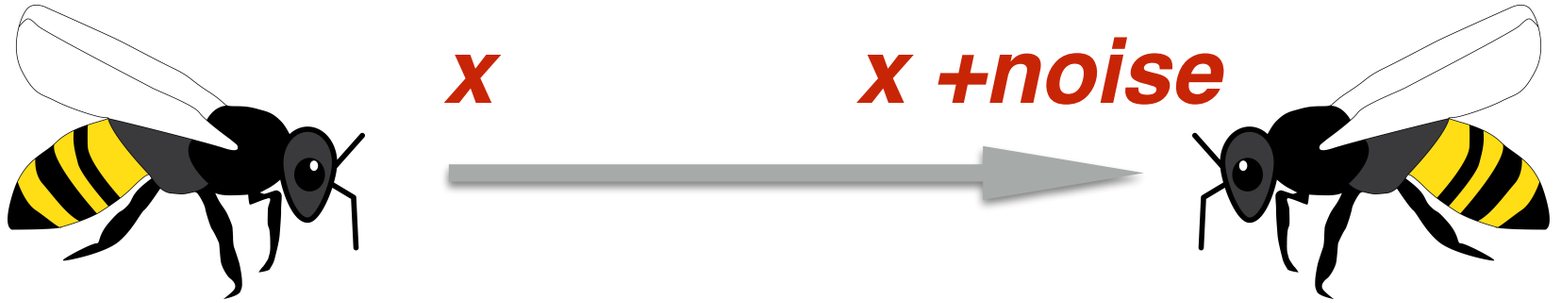
Evidences for both direct and indirect (distributed) sensing of environment

Passive communication

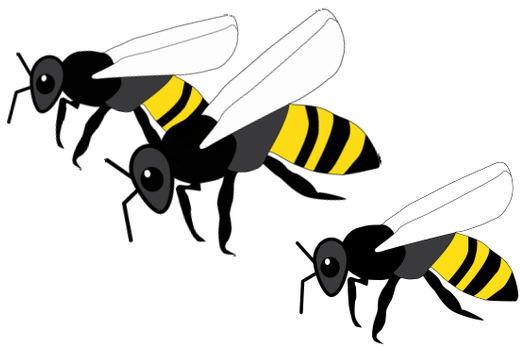
Information is received by observing the behavior of others

Active communication

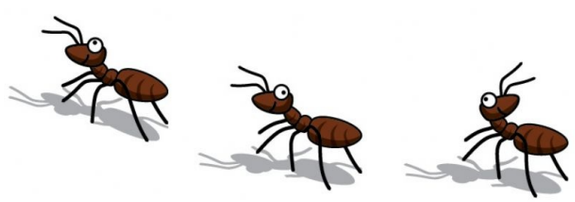
Noise in communication



How do biological ensembles overcome noise in communication?



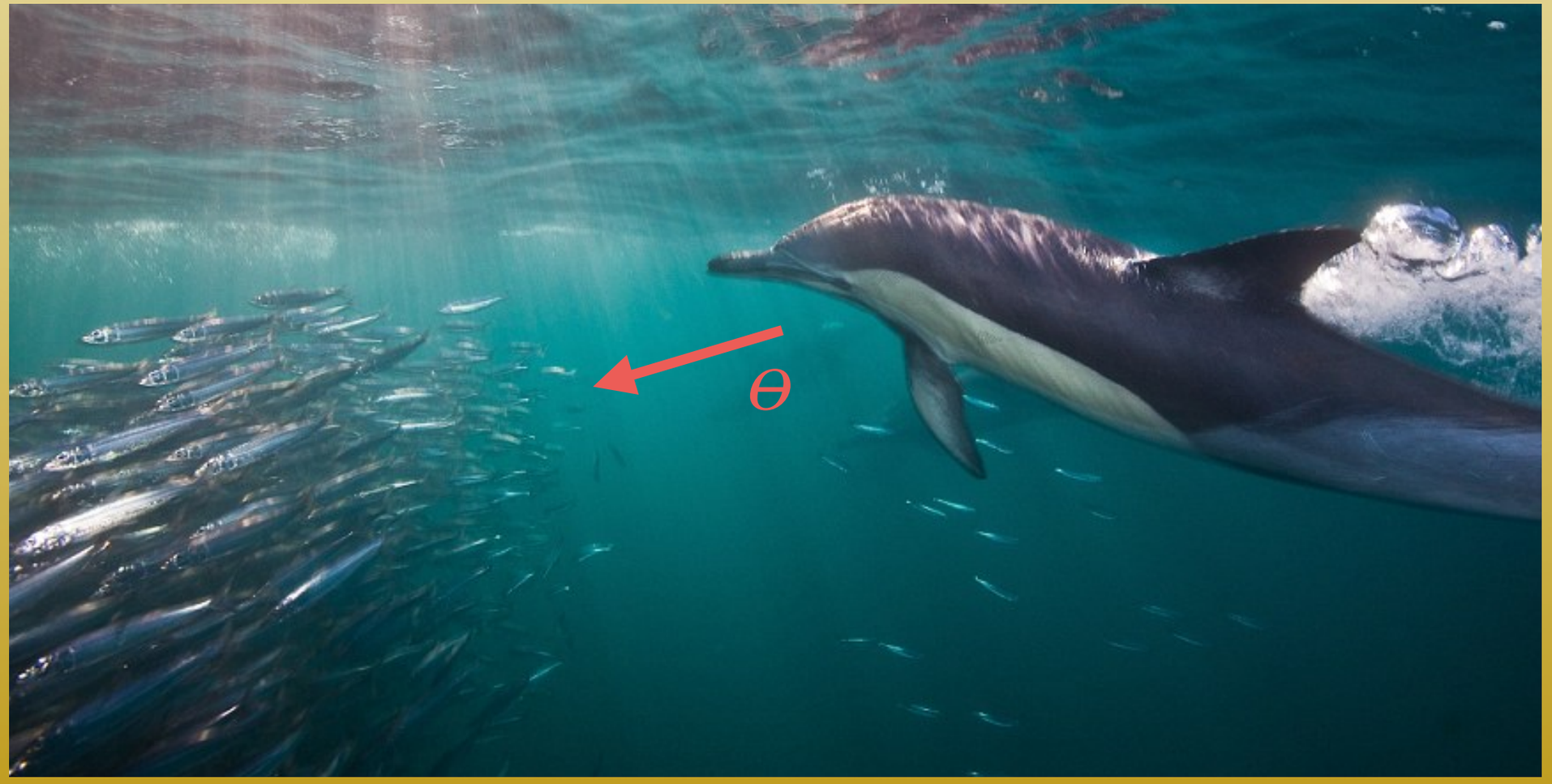
Information theory seems like to right language



The Distributed Estimation problem

***Goal:* estimate an environmental value θ**

(e.g., a direction away from a predator)



Informally

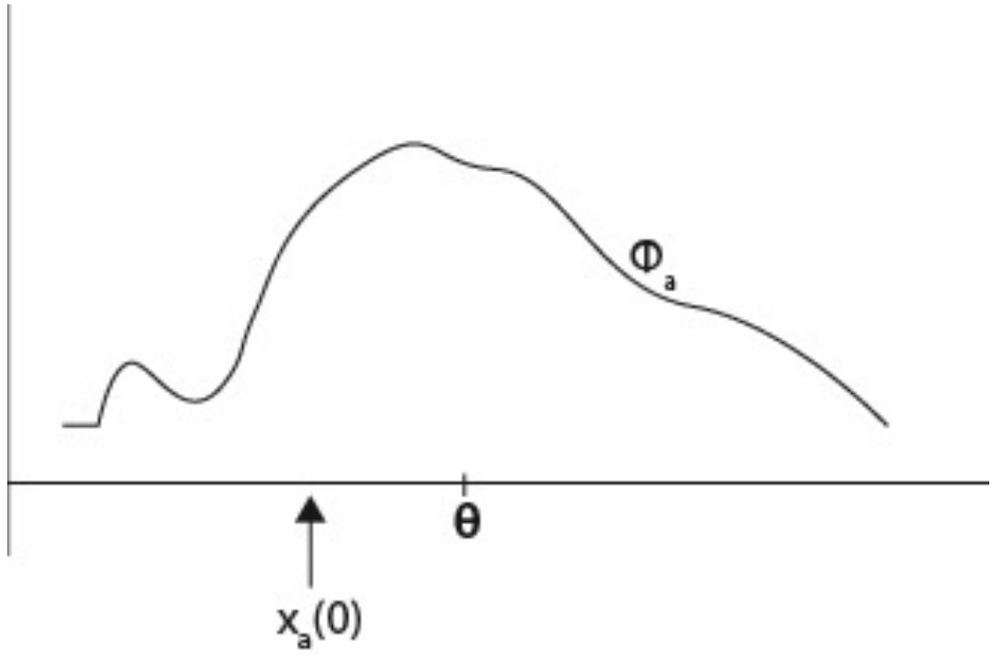
- Agents have **initial unreliable estimates** of Θ and try to improve their knowledge by communicating

- Agents can have **noisy observations of others** (passive communication)

- Agents may communicate **extra information** (active communication)

More precisely

- An ``environmental'' target value Θ
- Each agent *a* keeps **an opinion $x_a(t)$** at time *t* (an estimator of Θ). At any time it can change its opinion by "*shifting*".
- Initially, the opinion $x_a(0)$ is taken from some distribution around Θ



- Agents use communication to improve their estimates of Θ

Goal: Keep estimators $x_a(t)$ unbiased and minimize variance

The communication

Noisy passive communication: When *a* views *b* it obtains a relative and noisy distance measurement:

$$d_{ab}(t) = x_b(t) - x_a(t) + \eta$$

(the noise η is taken from a distribution $N(\eta)$ centered at *0*)

Can add active communication based on history

Independent meeting pattern:

A → B

$$\text{History}(A) \cap \text{History}(B) = \varnothing$$

capture well short time scales in dynamic and well mixed settings, where each agent views only few others

Competitive analysis

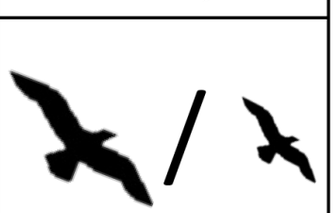
We want to identify simple algorithms that perform "well"

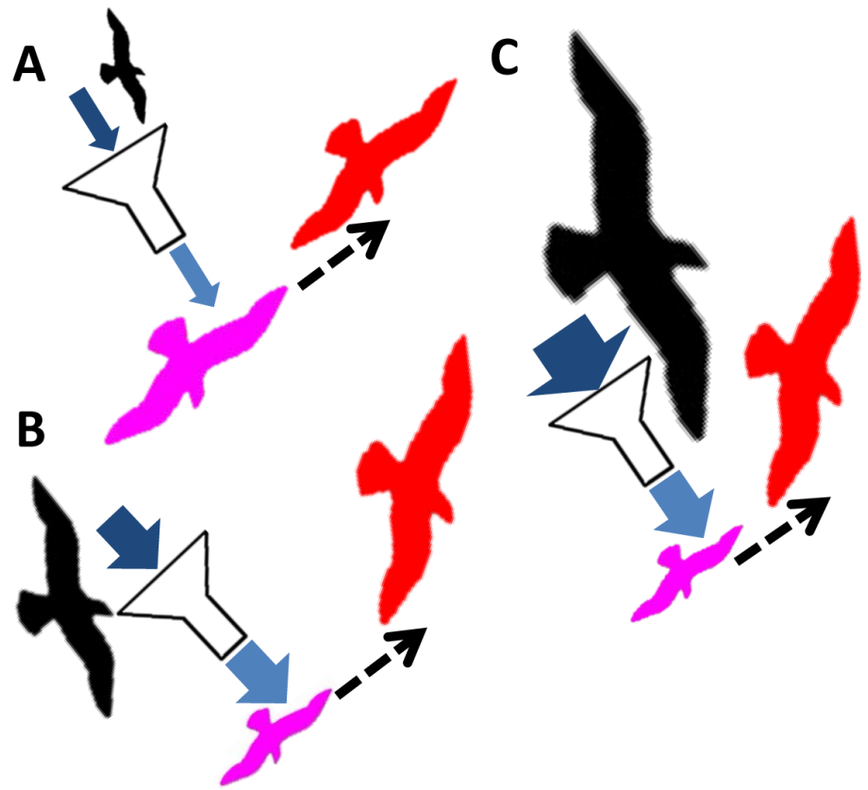
We compare algorithms to Algorithm OPT - the best possible algorithm in the most liberal version of the model: OPT communicates all memory and history of agents and may potentially perform complex calculations to find the best estimate for θ

Results

Fisher Channel Capacity

Fisher Channel Capacity is defined as J_N.
Since $J_a(t+1) - J_a(t) \leq 1/(1/J_b(t) + 1/J_N) \leq J_N$, the increase in Fisher information is always at most the Fisher Channel Capacity.

External state (orientation)	X_a, X_b	
Agent relative information (large/small)	J_a^Θ	
Maximal Information sent	J_b^Θ	
Channel Capacity	J_η	
Maximal information received	$\frac{1}{\frac{1}{J_b^\Theta}+\frac{1}{J_\eta}}$	



Lower bounds on performances

An extremely simple and near optimal algorithm

Algorithm *CONF* is based on maintaining and transmitting a confidence parameter $c_a(t)$ associated with the accuracy of the estimation $x_a(t)$. Updates are made by performing weighted average procedures.

Using lower bounds on the **Fisher information,** we show that such a method can lead to almost optimal performances

In particular, **if all distributions are Gaussian** then for every agent at any time, **Algorithm CONF has the same variance as OPT!**

Evidence for confidence storing and sharing in animals

Internal representation of confidence

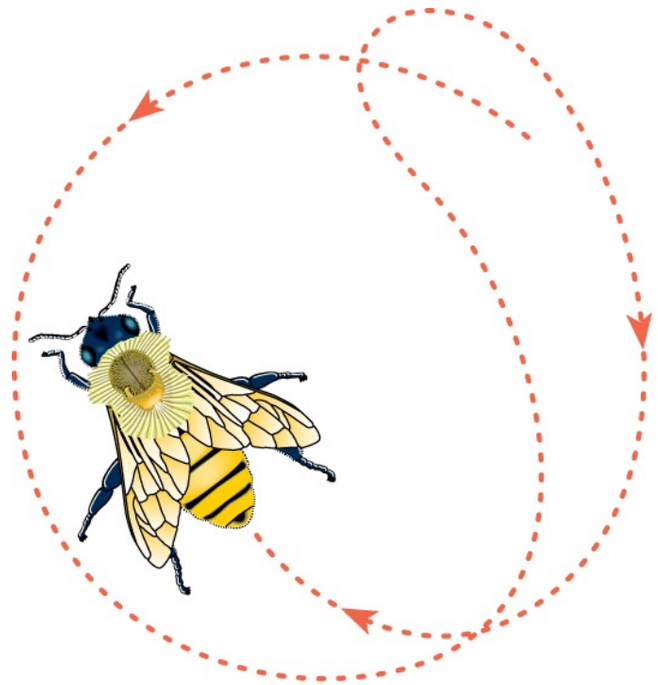
Experiments were conducted on **fish and bugs**, in which the experimentalists **confused** some of the animals and saw that these animals were **more responsive** to social information

Golden shiners [Couzin et al, Science 2011]
Sticklebacks Fish [Bergen et al. Royal Society, 2014]

Cactus bugs [Fletcher & Miller, Biology letters 2008]

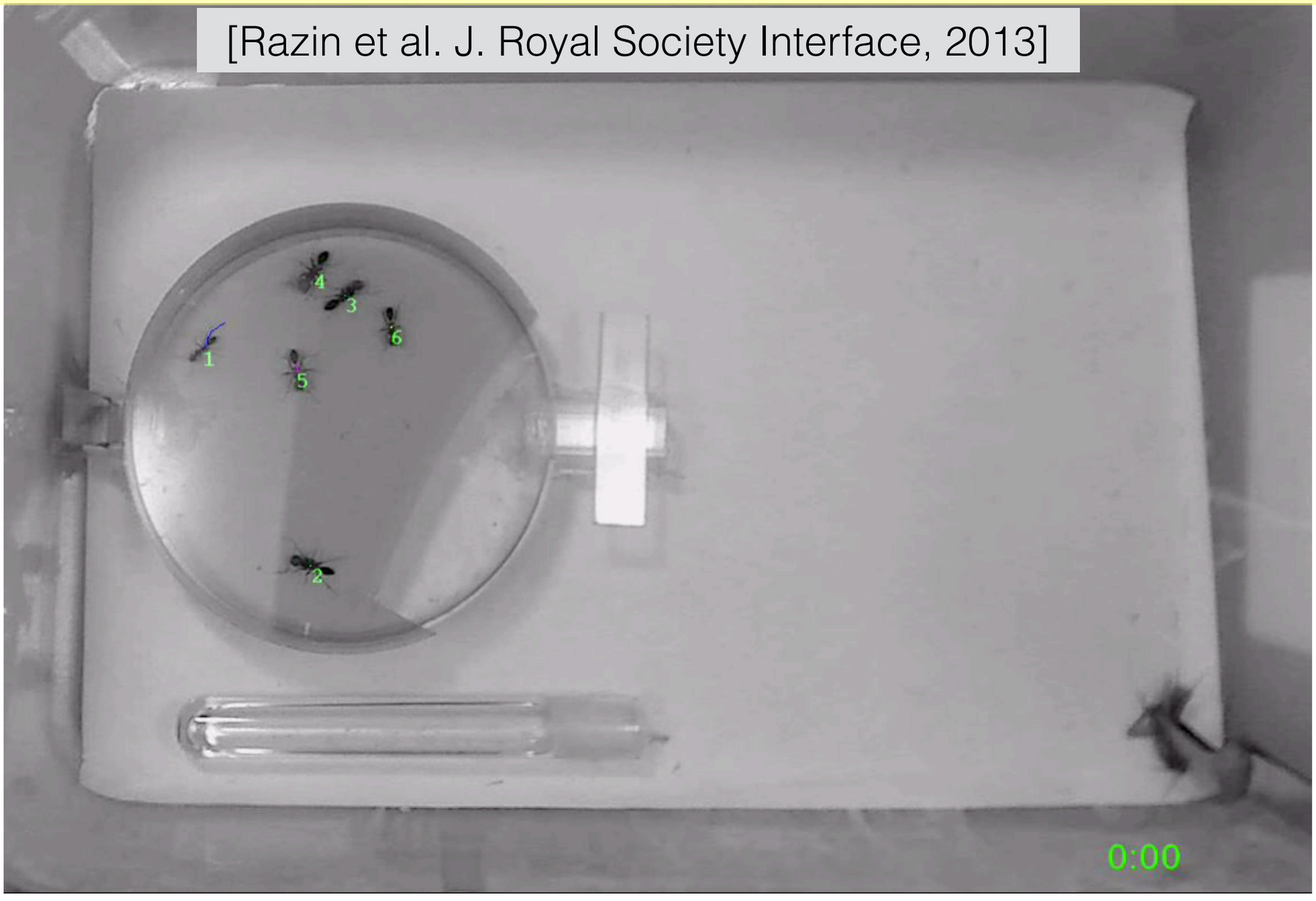
Speed = Confidence?

House-hunting in honeybees *Apis mellifera*



Confidence in recruitment: A correlation between the speed of a bee flying to the prospect site and the responsiveness of other bees.

Recruitment behavior in the desert ant *Cataglyphis niger*



Speed = Confidence?

- High speed is correlated to high probability of exiting the nest
- Very high speed is correlated to direct contact with the food
- Speed increases after interaction with a fast partner

Merci!